AD 414505

FTD-TT-63-351

TRANSLATION

EFFECT OF A MAGNETIC FIELD ON PHENOMENA IN A DIODE WITH CESIUM VAPORS

By

N. D. Morgulis and Yu. I. Chutov

FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

WRIGHT-PATTERSON AIR FORCE BASE

OHIO

FTD-TT- 63-351/1+2

UNEDITED ROUGH DRAFT TRANSLATION

EFFECT OF A MAGNETIC FIELD ON PHENOMENA IN A
DIODE WITH CESIUM VAPORS

BY: N. D. Morgulis and Yu. I. Chutov

English Pages: 16

SOURCE: Ukrainian periodical, Ukrains'kiy Fizichniy
Zhurnal, Vol. 7, Nr. 9, 1962, pp 1003-1012

S/185-62-7-9

THIS TRANSLATION IS A RENDITION OF THE ORIGINAL FOREIGN TEXT WITHOUT ANY ANALYTICAL OR EDITORIAL COMMENT. STATEMENTS OR THEORIES ADVOCATED OR IMPLIED ARE THOSE OF THE SOURCE AND DO NOT NECESSARILY REFLECT THE POSITION OR OPINION OF THE FOREIGN TECHNOLOGY DIVISION.	PREPARED BY: TRANSLATION DIVISION FOREIGN TECHNOLOGY DIVISION WP-AFB, OHIO.

FTD-TT- 63-351/1+2 Date 19 June 1963

B

EFFECT OF A MAGNETIC FIELD ON PHENOMENA IN A DIODE WITH CESIUM VAPORS

by

N. D. Morgulis and Yu. I. Chutov

The effect of a magnetic field on an electron short circuit stream and on the characteristics of the entire strear was investigated in a decelerating electric field in a diode with cesium vapors as a close model of a thermoelectron energy transformer; an interpretation is given on the obtained expreimental results.

Investigations of the nature of thermoelectron transformation of thermal energy into electric requires a general explanation of the role of various physical phenomena,which take place on the surface of converter electrodes and in its interelectrode space as well. Concentrating recently attention on diversified,and important for the operation of such a converter, phenomena in cesium plasma, which ordinarily fills up its interelectrode space, we have now turned to the question regarding the effect of a magnetic field.

Questions regarding the ffect of a transverse magnetic field on the performance of a thermoelectron converter with cesium vapors, attract immediately the attention in connection with the fact that: 1) in such a way it is possible, in principle, to obtain directly in the converter a variable stream of necessary frequency, influencing it with a variable magnetic field [1] and [2] in accordance with the theoretical analysis made by [2] on the formation by the converter current an eigen magnetic field since this may to a considerable extent affect its operation. Fortunately the last ones are not so dangerous, because the calculation mentioned in [2] was made in pure vacuum approximation, while a similar transformer functions ordinarily in the presence of interelectrode cesium plasma in it , where the effect of the magnetic field should be much lower. This fact for one case has already been explained long ago

expreimentally in [3] and only recently theoretically 0 in report by [4] . In connection with the great interest to this problem on the whole we explained in this report its investigation to greater length. Recently have been carried out a series of interesting investigations on the effect of a transverse magnetic field on bipolar diffusion in cesium plasma [5]. There is no direct relation between our case of monopolar diffusion of electrons to the anode of the converter with cesium plasma and this investigation.

The experimental instruments used by us for the basic measurements, alike in [3] were cylindrical diodes with cathode with tungsten filament of a radius of 0.15 mm, made burning hot, as usually in these cases, in one of the AC semiconductors; the anode was made of tantalum and represents a cylinder with protective rings with a radius of 4 mm. For a more detailed examination of phenomena, which have been observed by us into part of the instruments was inserted a small movable cylindrical sonde (probe) similar to the one described in [6] ; the latter could move in the central part of the interelectrode space along the given radius with the aid of a corresponding movable system with screw threads, as is shown in fig.1 (here K - cathode, A-anode, OK - protective ring; A-probe; RS- - movable system).

We meant of utilizing this probe for designations, as in [6], distribution in space of parameters of our plasma in various conditions of the experiment. The pressure of cesium vapors in the device p established by the temperature of its bottle t within limits of 25 - 240°C would be 10^{-6} - 0.3 mm Hg. The short circuit current density close to the point of saturation was on the surface of the cathode I_o and controlled by its temperature T_k and by the pressure p' and varied within limits of from 0.02 to 2.0 a/cm^2. Near the surface of the anode current density was approximately 25 times smaller. The instrument was situated in an axial magnetic field , which reached 400 e, which perfectly sufficient for the examined problem; this is evident at least from the fact that : 1) Larmor radius $\rho = \frac{1}{H}\sqrt{\frac{m}{2eV}}$ at H = 400 e and electron energy in our case V_e = 0.25 - 1 ev does not exceed 0.1 mm, then $\frac{R}{\rho} \geqslant 40$ and (2) maximum

eigen magnetic field $H_n = 0.63$ IR of typical disk section of converter with R = 3 cm and I = 30 a/cm^2, which with the summery current of 850 a equals 60 e. In connection with this it should be said, that a similar cylindrical diode with cesium vapors is, ordinarily, a model for concrete real converters, consequently its utilization as a model of a similar converter under the very same working conditions is quite handy and advisable for studying the physics problem given in this report.

We shall begin examining this problem with the case of two actually variable cesium vapor pressures. : $p = 3 \cdot 10^{-4}$ mm Hg (t = 90°C) and p = 0.3 mm Hg (t = 240°C) and quite close short circuit current values I_o. Since I_o is regulated by cathode temperature changes T_k the, as is evident from the known adsorption dependence $I_o = f(T_k)$ the function of the electrone outcome from the cathode φk changes here, and it means also the contact difference of potentials ΔV_k[7]. In a similar way was determined the dependence of the short circuit current I_o upon magnetic field intensity H at certain values I_o. The dependences I/I_o obtained thereat $I/I_o = f$ (H) are given in fig 2. Curve I corresponds to t = 90°C, I = 0.3 a/cm^2 and T_k = 2500°K (small circles), and I_o = 1.5 a/cm^2 and $T_k >$ 2500°K (small crosses); curve II - t = 240°C, I_o = 0.4 a/cm^2 and T_k = 1700°K; curve III - t = 240°C, I_o = 2.5 a/cm^2 and T_k = 2500°K.

It is eviden from fig 2 that at a quite low pressure (curve I) and $T_k \geq$ 2500°K when the free run of the electron[8] $\lambda_e \gg R$ and contact difference of potentials $\Delta V_k = \Delta V_{kmax} \approx 2.5$ v $I/I_o = f$ (H) decreases regardless of I_o. That is why these decreases are always slower than in case of vacuum[3], because the intensity of Hell's critical magnetic field equals $H' \approx 25$ e. In conditions corresponding to curve II fig.2. where, on the contrary, $\lambda_e \ll R$ and $\Delta V_k \leq$ 1b, and I_o = 0.4 a/cm^2 (same as in one of the instance of curve I), the form of the curve $I/I_o = f(H)$ changes noticeably and the tempo of its sloping slows dow condiderably. It becomes similar to the one obtained in case of bipolar diffusion of helium plasma to the walls in a magnetic field[9] although in our case we have dealings with monopolar diffusion of electrons to the anode. Otherwise, in case of curve III, when $\lambda_e \ll R$, but ΔV_k = 2.0

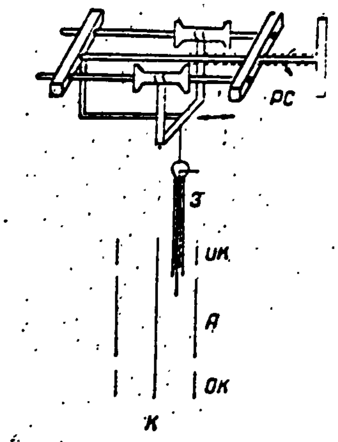


Fig.1.

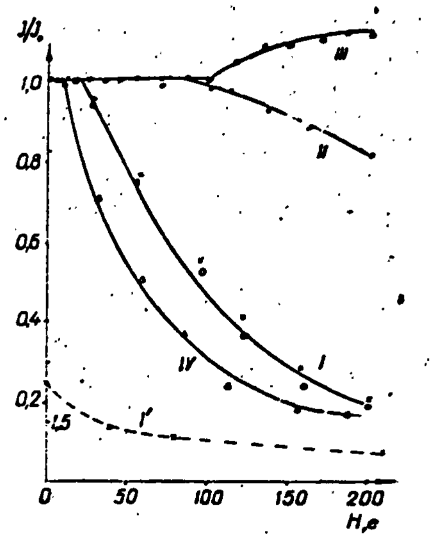


Fig. 2.

= 2.5 v and $I_0 = 2.5$ a/cm^2 (approximately the same as in another case of curve I), the picture changes radically-here is even observed of noticeable rise in curve. The latter is explained apparently by the fact that during change over from curve II to curve III both I_0 and ΔV_k increase (as result of partial desorption of cesium layer from the surface of the cathode). In this way, are formed favorable conditions for the origination of an intensive cesium arc discharge [6] as in magnetron sources of positive ions. Positive ions in this case can cause additional neutralization of the still existing electron space charge near the cathode and possibly also additional red hot glowing of the latter, which may be the cause for additional rise in curve III. On the other hand, it could be expected that an opposite role in this case will be played by an increase in electron diffusion on account of reaction not only with atoms, but with considerably more effective in this respect cesium ions. By comparing the cross sections of diffusion of electrons by atoms $Q_a = n_a q_a$ and by ions $Q_i = n_i q_i$ it becomes evident, that for q_a = 5 $\cdot 10^{-5}$ cm^2 and $q_i = 1.5 \cdot 10^{-12}$ cm^2

and $n_a = 6 \cdot 10^{15}$ cm^{-3} and $n_i = 5 \cdot 10^{12}$ cm^{-3} [6], $Q_a \approx 30$ cm^{-1} and $Q_i \approx 8$ $cm^{-1} < Q_a$. In this scattering of electron by cesium ions there should be no decisive role here. As is evident from above statement, the transition into arc mode of operation of the converter is favored not only by an increase in cesium vapor pressure [6] but a rise in electron stream density and contact difference of potentials. It should be said, that in condition $t = 90°C$, $T_k > 2500°K$, $I_o = 1.5$ a/cm^2 easily originate high frequency oscillations with a frequency close to 100 kc and initial amplitude $j_o = 0.3$ a/cm^2. On these oscillations (we studied same in [10]), which have, apparently, a temporary nature is also exerted an effect by the magnetic field; dependence $J/J_o = f(H)$ is shown in fig.2. by curve IV. Making so far no final conclusions we nevertheless call attention to the hyperbolic nature of the curve IV, in field $Q < R$, then $H > 10$ e, which is in conformity with the diffusion theory [11] for the reaction of oscillatory nature.

The above listed characteristics of diodes with cesium vapors in a magnetic field appear also on the dependences of ratio I/I_o' upon the retarding outer anode potential V_a at various H (I_o' corresponds to $V_a = 0$); these dependences characterize the working condition of the converter. Similar dependences for $t = 90°C$ and $I_o = 0.3$ a/cm^2 are presented in fig.3 in form of continuous curves 1,2,3,4,which correspond to $H = 0$; 40, 80; 210 e. As in case of curve I fig.2. when changing over from $I_o = 0.3$ a/cm^2 to $I_o = 1.5$ a/cm^2 the form of the curves fig.3 remains unchanged.

Just like curve I fig.2 the family of curves 1-4 fig.3 has qualitatively the very same nature as in case of a vacuum diode. Actually, curve I, which corresponds to $H = 0$, as if points toward the free movement of electrons from cathode to anode. It breaks away at $V_a = 2.5$ v, which as it could be expected, is practically equal to the contact difference of potentials $\Delta V_k = 4.5 - 1.8 = 2.7$ v between pure and red hot to $T_k = 2500°K$ tungsten cathode and the cold tantalum anode covered by a cesium layer. And in this way, the process of the corrected anode potential $Va' = \Delta V_k - V_a$ is fixed by the lower and recurring scale along the axis of the abscissa fig.3. At a gradual rise in magnetic field H the zone where each curve originates is displaced in the

direction of more positive values of the corrected anode potential Va', as it should take place in case of vacuum.

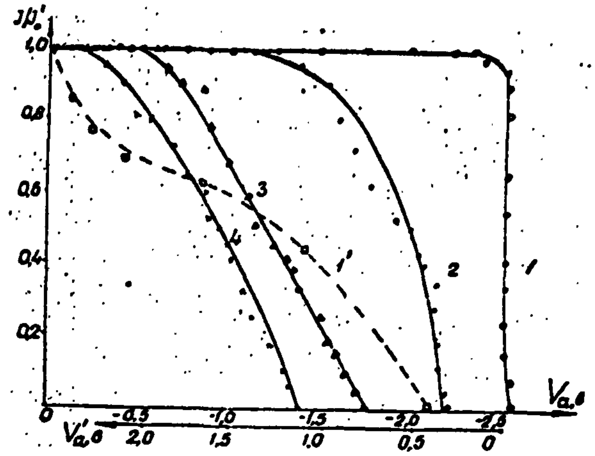


Fig.3.

It should be remembered here that for the specific distribution of potential in interelectrode space [6] which is characterized by the presence of plasma and near anode potential jump. The sharp descend in curves fig.3 to the axis of the abscissa can be explained by the fact, that in these conditions over the electron stream is superimposed a noticeable stream of cesium thermo ions. In accordance with data in fig.3 with the rise in H there is slow reduction in maximum output load V_m [7] which is important for the operation of the converter; the dependence $V_m = f(H)$ obtained by us is indicated by the dotted curve 1' in fig.2. The dotted curve I' in fig.3 in dicates the dependence $I/I_o = f(V_a)$ at H = 0 for high frequency AC current, which corresponds to conditions of curve IV fig.2. In this case, as in [10], the value V_m appeared to be smaller, than in case of curve 1 fig.3., and the very $V_m \approx 0.9$ v.

Much more complicated were found to be curves $I/I_o' = f(V_a)$, obtained in case of a decelerating field in conditions where they correspond to curves II and III fig.2 i.e.at t = 240°C; they are shown in fig.4, where H = 0,40, 80 and 210 e, and correspond to various designations. First of all we want to call attention to the fact that in contrast to the case where t = 90°C, at t = 240°C I/I_o' does not depend upon the value H in the indicated range of its values. This, is possibly, explained

by the fact , that at $\rho \ll R$ the magnic field affecting the electron diffusion coef ficient D_e and the magnitude of electron stream - from the cathode to the anode of our diode (alike the electron stream from plasma to somewhat positive probe [11]

$$I_s = e2\pi Rl\left(1+\frac{T_p}{T_e}\right)D_e\left(\frac{dn_e}{dr}\right)_R, \quad (1)$$

does not actually affect the characteristic of their respective distribution according to energies, which is quite probable.

Curve II fig.IV, which corresponds to small I_c=0.4 a/cm^2 has, like in case of vacuum, a horizontal part, which extends to V_a = 0.8 v.

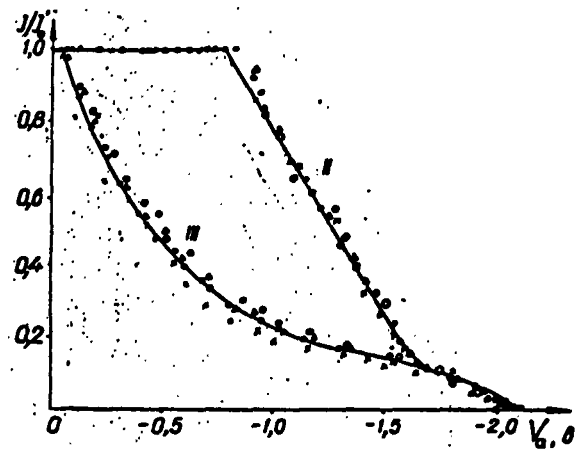


Fig.4.

The presence of an initial horizontal plot in curve II fig.4., as is evident from examining the dependences I_0=f(T_k) [7], is connected with the existence in these conditions with an accelerating electron contact potential difference, which equals approximately 0.8 v. Since it is noticeably smaller than the potential of cesium atom excitation (V_b = 1.5 v), then all collisions between electrons and atoms have only an elastic (without noticeable energy losses) nature. In the zone of existence of accelerating electric field potentials formed by this potential difference is possible, apparently, a drift of all electrons which came out from the cathode, to the anode [12], just as in case of quasivacuum condition [6]. When changing over to the condition corresponding to curve III in fig.4, the contact difference of potentials

rises ($\Delta V_k \gtrsim 2.0$ v) and already exceeds values V_b for cesium. Together with the in-crease in I_o and p this leads to the origination of an intensive shock (gradual) ionization, that is to the formation of of arc condition [6]. The basic mass of electrons of the short circuit current which originate in this case, have now quite low natural (eigen) energy; this is also due for the sloping of curves III. Surprising is the presence in curve II of such a "long " tail, which at values V_a converges with curve III. The impression arises, that this is due to thermo electrons with local cathode sections from which the film has been removed. It is interesting to point out, that the optimum output load V_m in cases II and III was revealed with an identical V_m = 0.9 v, it ordinarily does not depend upon H. For the additional rôle which in this case is also played by an increase in the cross section of electron diffusion on account of reaction not only with atoms, but also with cesium ions, we have already stated before.

In favor of the above considerations relative to curves II and III fig.4 speak also the values of parameters obtained in these conditions by interelectrode plasma, i.e. concentration n_e and temperature T_e its electrons and space potential V_p of the espective anode. With this method were measured probe characteristics in conditions close to data given in fig.4, and the ones, at t =210°C, H = 0 and I_o =0.05 a/cm^2 (II') and I_o = 1.5 a/cm^2 (III') at a certain average position ($r = \frac{1}{2} R$) of the probe: the obtained characteristics are plotted in fig.5 (their scale along the axes of the ordinates are different). It is evident from fig.5, that for the characteristic II' $n_e = 2 \cdot 10^{19}$ cm^{-3}, T_e=5000°K, V_p=-0.35 v, and for III' $n_e = 2 \cdot 10^{12}$ cm^{-3}, T_e=2800°K and V_p = + 0.55 v. These data in conformity with the ones obtained by [6] show, that in case II' we actually have quasivacuum, and in case III' - and arc operating condition of the diode and that the transition from condition II' to condition III' is connected not only with the rise in cesium vapor pressure rise, but also (at higher pressure) with the rise in force of the electron stream and contact difference of potentials.

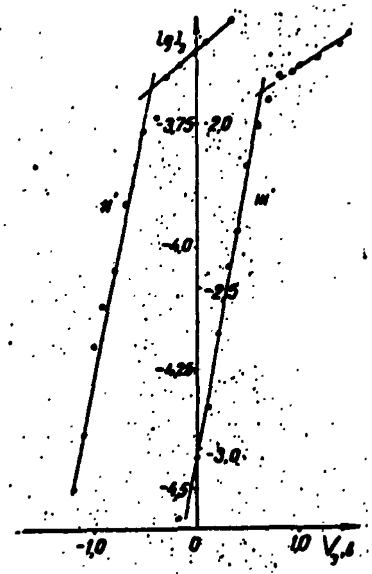


Fig.5.

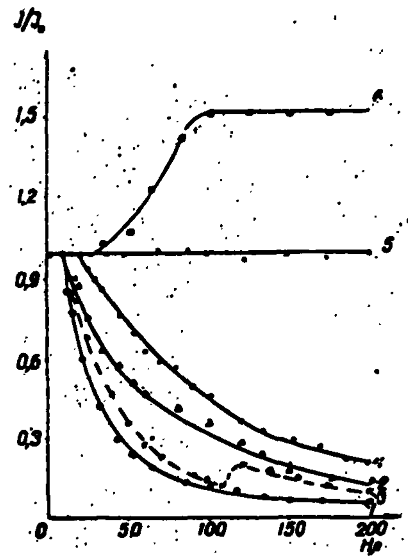
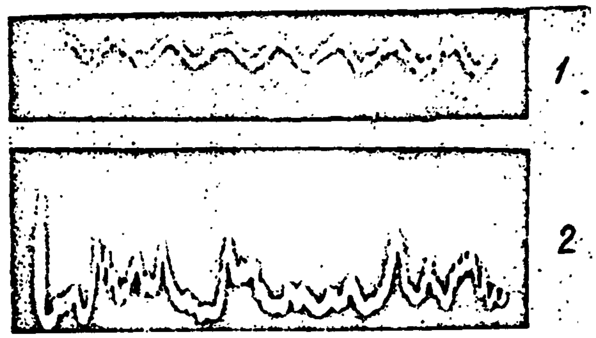


Fig.6.

In fig.6 is shown the dependence of respective short circuit current values I/I_0 upon the value H at various cesium vapor saturation temperatures (1 - 25°C, 2 - 90°C, 3 - 120°C, 4 - 150°C, 5 - 180°C, 6 - 210°C), but at identical I_0 = 0.6 a/cm² and T_k = 2500°K. Only in case t = 25°C I_0 = 0.15 a/cm² as result of insufficient neutralization of electron space charge by cesium ions and at t = 210°C T_k = 2200 °K as result of partial formation on the cathode of a cesium film. Curve 1 ($p \approx 10^{-6}$ mm Hg) has a practical vacuum nature , since at H_{crit} = 25 e, according to Hell, $I/I_0 \approx 0.5$. With an increase in t to 150°C (except of case where t = 120°C) there is a regular ascent of the entire curve, due to regular increases in the degree of electron diffusion, as it has been observed for example in [9] . In the zone t = 150 - 180°C ($p = 1 - 3 \cdot 10^{-2}$ mm Hg) is a sharp rise in the curve , connected, apparently, with the transition from quasivacuum to arc condition [6], where intensive impact ionization originates in volume. Finally, in the zone t = 180-210°C is a further ascent of the curve analogous to that described in fig.2, i.e.$I/I_0 > 1$. The nature of the stream in

the decelerating field, which corresponds to these temperatures, changes regularly from the characteristics given in fig.3 to the ones given in fig.4.

In case $t = 120°C$ and $I_0 = 0.6\ a/cm^2$ the dependence $I/I_0 = f\ (H)$ has an anomalous character (dotted curve 3 in fig.6). This can be explained by the origination of sharply expressed oscillations (fluctuations)[10]. In the zone of the curve up to the observed here deformation ($H \leqslant 100$ e) these oscillations with a frequency $v \approx 120$ kc have a periodical, though also sharply nonsinusoidal nature (illustration 1 fig.7). They are considerably different from the observed by us oscillation of temporary nature [10] at the very same t, H=0 and close to the flat system of electrodes. On the other hand, at $H > 12$- e these oscillations acquire a clearly expressed noise nature, as it is evident from illustration 2 fig.7.



GRAPHIC NOT REPRODUCIBLE

Fig.7

It is possible, that exactly in this case ($t \approx 120°C$), ordinarily purely qualitative, should take place the described in [11] mechanism of diffusion in the magnetic field during interaction of oscillatory nature and with hyperbolic dependence $D_e = f(H)$. These phenomena, which do take place here, are highly complex, and it is also evident from fig.8 how the family of stream characteristics is plotted in the decelerating field at $t = 120°C$ and different H (0-1, 40e-2, 80e-3, 210e-4). We do not have at this moment sufficiently convincing proof regarding the nature of these facts and that is why we leave these questions unanswered.

In fig.9 are plotted dependences I/I_0 upon H for the case $t = 210°C$ (p=0.1 mm

Hg), when $\frac{R}{\lambda_e} \simeq 10$, and different cathode temperarures, T and short circuit currents connected with it I_0. Curve 1 corresponds to $T_k = 1100°K$, $I_0 = 0.02$ a/cm^2, 2 - 1320° K, I = 0.09 a/cm^2, 3- $T_k = 2160°K$, I_0=0.09 a/cm^2, 4 - 2480°K, J_0=1.3 a/cm^2, 5- T_k = 2550°K, I_0=1.7 a/cm^2. When analyzing these dependences it is necessary to include the adsorption dependences of the short circuit current I_0 upon T_k[7] at t = 210°C with maximum at $T_k^{\prime}$ = 1400°K and sharp rise at $T_k^{\prime\prime}$ = 2100°K. The temperature T'_k= 1400°K characterizes the beginning of noticeable cesium film description from the tungsten liner, and $T_k^{\prime\prime}$ = 2100°K - transition into the field of total desorption. It can be shown, that curve 1 corresponds to such a state of the cathode, which at the Richardson constant A = 3 a/cm^2.degree^2 characterizes the function of electron output φ_k = 1.8 ev, i.e. contact difference of potentials relative to the anode ΔV_k=0 (considering, that φ_a = 1.8 ev), curve 2 in this case A - state ,which is characterized φ_k = 2.0 ev, i.e.ΔV_k= 0.2 v, and curves 3-5 at A = 120 a/cm^2.degr^2 - state which is characterized by constant values φ_k= 4.2 v, i.e.ΔV_k = 2.4 v; all these data are in perfect agreement with the known data for the Cs-W system:

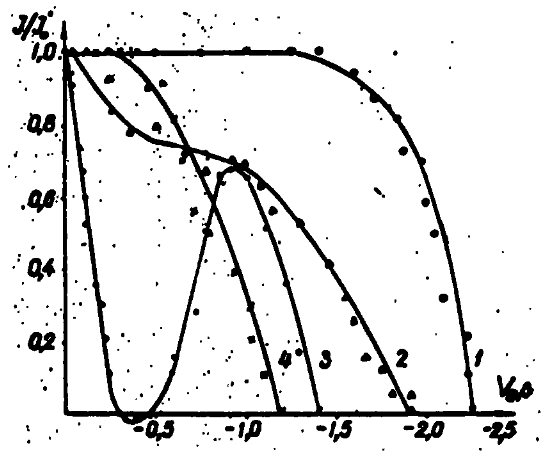


Fig.8

An analysis of curves fig.9 leads us to a series of interesting conclusions. First of all it is revealed that the slope of curve 1 corresponds qualitatively very well with the theoretical [15] :

$$D = \frac{D_0}{1 + \omega^2\tau^2} = \frac{D_0}{1 + (\lambda_e/\rho)^2}, \qquad (2)$$

if it is consideredthat the stream through the diode is proportional to the diffusion coefficient D. Actually, if ρ is known, then on the basis of comparing formulas (2) with investigation data it is possible to designate λ_e , and by it the effective cross section of electron diffusion by cesium atoms Q_a. It appeared to be equal approximately to 100 cm^{-1} at p = 1 mm Hg; these values are in quite good conformity with the ones obtained in [8] . In this respect out investigations correspond also with data of [9, 14] which proved validity of formula (2) for the case of monopolar diffusion of weak electron streams in a transverse magnetic field. When changing over from curve 1 to 2 we observed a slight rise in curve, typical for the case of rise in stream at practically unchanged conditions [9].

The change over from curve 2 to 3 is interesting by the fact , that in this case at unchanged I_0 and p (at $\lambda \ll p$), there is a sharp rise in contact difference of potentials ΔV_k. The path ofthe curve is sharply different from 2 - curve 3 rises sharply upwards as result of the above mentioned transition from quasivacuum to arc mode of operation at which in the volume originates intensive impact ionization. Curve 4 analogous to curve III fig 2 and curve 6 fig.6. Finally, curve 5 fig.9 with the rise in H no longer has a maximum, apparently, as result of the fact, that in this case already from the very beginning there is a saturation stream and the potential minimum is entirely absent.

It is evident from above stated, than at analysis of physical phenomena, which do interest us, is actually complicated by the fact, that by the very complicated effect of the magnetic field on the diffusion of electrons there is still an additional difficulty, insufficiently controlled, influence of ionization phenomena in volume. In accordance with formula (1) from analyzing the stream in the diode it is necessary to change over to direct analysis of the diffusion coefficient D_e. For this purpose it is also necessary to utilize the probe method considered by us before.

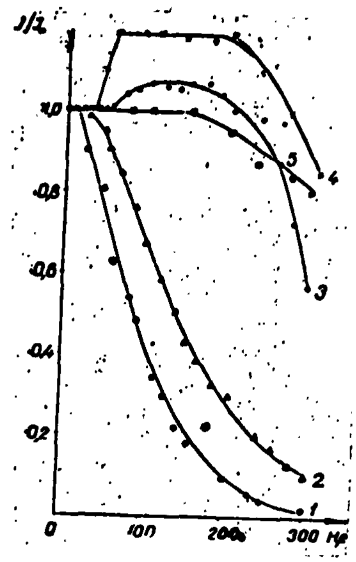


Figure 9.

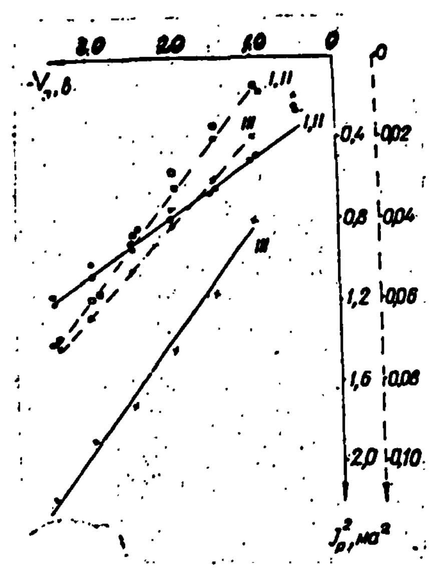


Figure 10.

This method allows to determine the distribution of charge concentrations $n_e = n_p$ and, it means, also their $\frac{dn}{dx}$ gradient. Unfortunately, such measurement in a magnetic field are complicated by the fact, that in this case can be utilized only ions of a part of the probe characteristic. Among other things during operation in our system of cesium fill coating the probe becomes heated somewhat (6) and because of this it can produce its own thermoelectron emission. This thermo electron emission may actually change the measurement results of relatively small ion of a negatively charged probe and in this way to a large extent hamper similar measurements. Because of this, we could not carry out systematic measurements of this type and we are compelled to confine ourselves only to cases when we succeeded in distributing the thermoelectron and ion streams of the probe. The concentration of charges was determined by the ion particle characteristic using the Langmuir method with the "attachment" of data obtained here at H = Oto data obtained from the electron part.

A felicitous example of similar measurements for the case of curve 5 fig.9 i.e. at $t = 210°C$, $T_k = 2550°K$, $I_0 = 1.7$ a/cm^2 in scale $I_p^2 = f(V_3)$, given in fig.10. The straight line I corresponds to $H = 0$, $I/I_0 = 1$, II-$H = 120$ e, $I/I_0 = 1$, III - $H = 400$ e, $I/I_0 = 0.7$. The solid straight lines pertain to the case when the feeler is at a distance $d = 2$ mm from the anode, dotted lines - for the case ,when $d = 0.5$ mm; to each group of straight lines corresponds a natural scale along the axes of the ordinates. It is evident from the drawing, that: 1) in conformity with the theory the dependence $I_p^2 = f(V_3)$ has a rectilinear nature; as the angular coefficient can be designated the concentration of charges n_p which has here conventional values [6]; 2) value n_p changes in the same manner as stream I,i.e.these values converge in cases of curves I - II and are smaller in case of curve III; 3) during the connection of a sufficient magnetic field there is a certain contraction of the plasma; 4)from the interrelation of streams and values $\frac{\Delta n_p}{\Delta x}$ obtained from investigations were designated according to formula (1) the ratios of diffusion coefficients at $H = 0$ and $H = 400$ e $D/D_0 \approx 0.3$; these values do not correspond to formula (2).

In this way, the physics data obtained in this investigation characterize favorably certain behavioral features of our diode with cesium vapors in the magnetic field as a sufficiently close model of a thermo electron energy transformer. It is particularly possible to point toward the fact that if in the future practical transformers of current type with cesium vapors will be capable of fucntioning in arc condition, which is quite probable, then the influence of the eigen magnetic field will be insignificant. In connection with this, the possibility of utilizing not a very large outer magnetic field for direct obtainment of AC current in the transformer of such type will, apparently,also be quite limited.

Literature

1. N.D.Morgulis, Uspekhi Fizicheskikh Nauk 70, 679, 1960
2. A.Schock, J.Appl.Phys.31,1978, 1960, Electr.Engr.79,973, 1960
3. P.M.Marchuk,Trudy Instituta Fiziki Akad.Nauk Ukr-SSR No.7, 3, 1956
4. G.Ye.Pikus,Zhurnal Tekhnicheskoy Fiziki 31, 1013, 1961.

5. L.Davies, Proc.Phys.Sov.B-66, 33, 1953; Yu.I.Aleksovskiy and V.L.Granovskiy; Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki 41,363, 1961; N.D'Angello and N.Rynn.Rev.Sci.Instr. 31, 1326, 1960; Physics of Fluids 4,275, 1303, 1961; R. Knechtli and J.Wada Phys.Rev.Let.6,215, 1961; Proc.IRE 49, 1926, 1961;

6. N.D.Morgulis, Yu.P.Korchevoy, Radiotekhnika i Elektronika 6,2073,1961

7. N.D.Morgulis; Yu.P.Korchevoy; Yu.I.Chutov, Zhurnal Tekhnicheskoy Fiziki 31,845 1961.

8. R.Brode, Phys.Rev. 34, 673, 1929; N.D.Morgulis; Yu.P.Korchevoy; Zhurnal Tekhnicheskoy Fiziki 32, 900, 1962

9. R.Bickerton and A.Engel.Proc.Phys.Sov B-69, 468,1956; I.Vasilyeva and V.L.Granovskiy, Radiotekhnika i Elektronika 4,2051,1959; 5,1508,1960.

10. N.D.Morgulis; S.M.Levitskiy; N.I.Groshev,Radiotekhnika i Elektronika 7,352,1962

11. D.Bohm; E.Burhop; H Massey; The Characteristics of Electrical Discharges in Magnetic Fields, N.Y.1949, p.49.

12. B.Ya.Moyzhes; G.Ye.Pikus; FTT 2, 756, 1960

13. J.Townsend, Phil.Mag.25,459, 1938; S.Chapman; T.Cowling. Mathematical Theory of Heterogeneous Gases, Moscow, Foreign Literature, chap.18,par.3 and 4.

14. R.Bickerton,Proc.Phys.Soc. B-70, 305, 1957

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE	Nr. Copies
HEADQUARTERS USAF	
AFCIN-3D2	1
ARL (ARB)	1
OTHER AGENCIES	
CIA	1
NSA	6
DIA	9
AID	2
OTS	2
AEC	2
PWS	1
NASA	1
ARMY (FSTC)	3
NAVY	3
NAFEC	1
PGE	12
AFCRL (CRXLR)	1
RAND	1

MAJOR AIR COMMANDS	Nr. Copies
AFSC	
SCFDD	1
DDC	25
TDBTL	5
TDBDP	2
AEDC (AEY)	1
SSD (SSF)	2
ESD (ESY)	1
RADC (RAY)	1
AFWL (WLF)	1
AFMTC (MTW)	1
ASD (ASYIM)	3

FTD-TT- 63-351/1+2